A new treatment approach for severe Legg-Calvé-Perthes deformity based on computer simulation and surgical navigation

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Legg-Calvé-Perthes is a hip disorder occurring in children, which causes deformity of the femoral head. For the surgical treatment of severe cases, a so-called femoral head reduction osteotomy (FHRO) can be performed in which a wedge needs to be resected to restore the sphericity of the joint. Although very good outcomes after FHRO have been reported, the surgery is rarely performed because preoperative planning and surgical execution are very challenging. Due to advances in computer-assisted surgery, new treatment concepts for FHRO could be developed which enable safer and more precise execution.

KEYPOINTS

- *Computer-assisted surgery can even drive the development of completely new treatment concepts such as for LCP.*
- *The computer-assisted treatment approach comprises a 3D preoperative planning stage in which the surgery is simulated in a patient-specific fashion.*
- *Based on the simulated surgery, patient-specific navigation instruments can be designed and 3D-printed.*
- *The instruments permit a more precise and safer execution of the surgery. Therewith it may help to further improve the results and hopefully encourages a more prevalent future employment of the FHRO worldwide.*

Legg-Calvé-Perthes (LCP) is a relatively common orthopaedic disease in paediatric hip disorders, with a prevalence of 1 case per 1200 children.[1] It has an onset between 5–10 years of age and it is caused by a disturbance of perfusion of the femoral head, leading to avascular necrosis (death of bone tissue) and deformations of the femoral head.[2] Revascularisation is slow and the necrotic bone undergoes fatigue fracturing, leading to flattening of the contour to an ellipsoid shape with an extra-large horizontal and a small vertical diameter. The femoral deformity initiates a reactive adaptation of the acetabulum.

Traditional treatment concepts for LCP range from conservative methods trying to keep the deformation as small as possible with mechanical unloading the joint,[3] to surgical methods trying to improve containment and therewith enlarge the load distribution area.[4]

Possible conservative treatments are adductor tenotomy, bracing and physical therapy. Traditional surgical methods, in turn, are femoral varus osteotomy, which realigns the femoral head relative to the hip socket, as well as pelvic osteotomies, to achieve adequate coverage of the femoral head. In one-third of the cases, however, the deformity of the head and the reactive acetabular deformity are too large and exceed the possibilities of traditional treatment concepts.

Deeper understanding of blood supply in the femoral head encouraged the development of a more effective surgical technique,[5] which permits to directly correct the femoral head morphology, rather than indirectly compensating overall joint functionality by altering the femoral shaft or pelvis. The so-called femoral head reduction osteotomy (FHRO) allows reshaping the head to its anatomical spherical shape by resection of the necrotic or deformed central part (Fig. 1).[6] The determination of the optimal correction, however, including definition of the segment to be removed and direction of the cuts to achieve the resection, describes an exceedingly difficult 3D (three dimensional) geometrical problem.

Conservative preoperative planning, which is based on analysis of plain

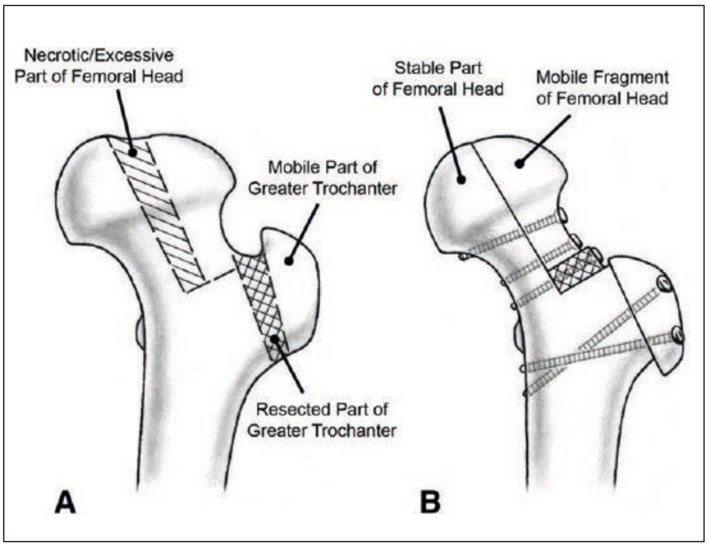

Fig. 1: Schematic view of a femoral head resection (FHRO) (modified from Ganz et al. 2009)[6]

radiographs or single computed tomography (CT) scans, cannot sufficiently capture the 3D problem. Moreover, it lacks appropriate tools for precise surgical implementation of the planned correction. These may be reasons why the number of cases treated with FHRO remains worldwide low considering the prevalence of LCP.[4]

Our previous work on computer-assisted surgery methods for complex orthopaedic interventions in upper[7-11] and lower[12] extremities paved the ground for the development of a new computer-assisted FHRO treatment method. We would like to describe the computer-assisted FHRO treatment approach on the basis of an example case of a LCP patient with severe deformation on the left femoral head. The patient was a 15-year-old female pupil. The severe deformity of her femoral head caused pain and forced her to give up rhythmic gymnastics, which she did semi-professionally since the age of 6 (Fig. 2A, B).

The treatment involves two components, computer-assisted preoperative planning in which every step of the FHRO is computer-simulated in 3D, and intraoperative navigation through patient-specific instruments (PSI) permitting a precise realisation of the planned correction.

Preoperative planning

In a first step, a 3D reconstruction of the pathological bone is obtained by segmenting CT data (Fig. 2B) using a commercial software (Mimics, Version 19; Materialise, Leuven, Belgium). The resulting 3D model (Fig. 2C) can then be imported into our in-house developed preoperative planning software CASPA (Computer Assisted Surgical Planning Application, Version 5; Balgrist CARD AG, Zurich, Switzerland), which is capable of precisely simulating each step of the surgical procedure in 3D. Thereby, the optimal osteotomy parameters can be established in a quantitative and objective fashion.

As shown in Fig. 3, the planning procedure is composed of the following steps: the placement of the osteotomy planes (Fig. 3A) such that the wedge (red) can be resected and the lateral fragment (purple) can be mobilized (Fig. 3B). The reduction of the mobile fragment to achieve a spherical femoral head is shown in Fig. 3C. In this example case, we used a mirror-model of the healthy contralateral femur as a correction goal (Fig. 3D). In case of bilateral deformities, we employ so-called statistical shape models (SSMs) to predict the pre-morbid anatomy. A SSM is built from femora models from a representative set of individuals in order to learn the anatomical variation between different subjects. This summation of all possible shapes can then be fitted to a new patient for predicting the healthy shape of the femoral head without pathological deformation. Restoring the sphericity of the femoral head is the main objective in the preoperative planning. Another challenge is to define the osteotomy planes without compromising the blood supply of the femoral head.[5] Additionally, a decent remaining neck diameter on the femoral shaft, approximately 1/3 of the pathological neck diameter, needs to be considered as well to ensure overall stability (Fig. 3C).

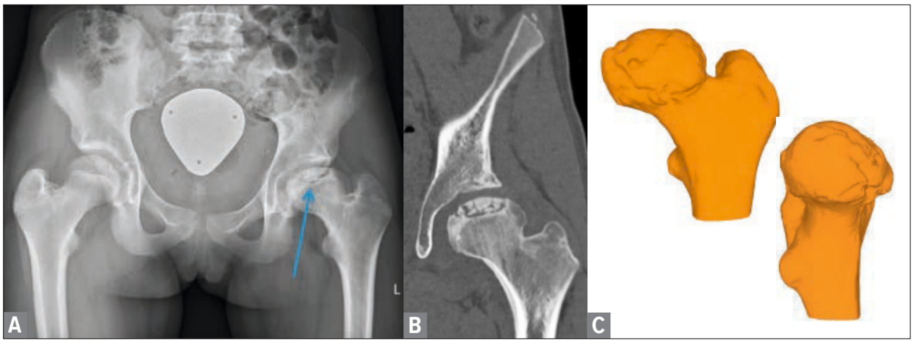

Fig. 2: A) X-ray image of the example case suffering LCP. A blue arrow indicates the location of the necrosis and the severe deformation of the femoral head. B) CT scan showing the pathological bone. C) 3D simulation permits examination of the bone form every perspective, hence provides more information of the pathology

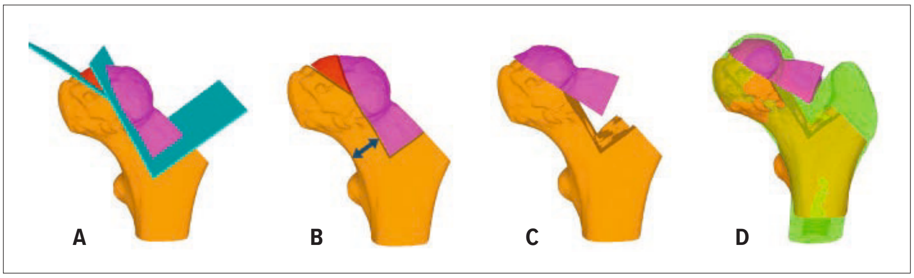

Fig. 3: Simulated outcome of the FHRO using computer-assisted preoperative planning, anterior-posterior view. A) Definition of osteotomy planes (cyan). Stable fragment (orange), mobile fragment (pink) and wedge to be resected (red). B) A sufficiently large remaining neck diameter must be considered (indicated by arrow). C) Final position of the mobile fragment, achieving a spherical femoral head. D) Mirror-model of contralateral femur, used as correction goal (green)

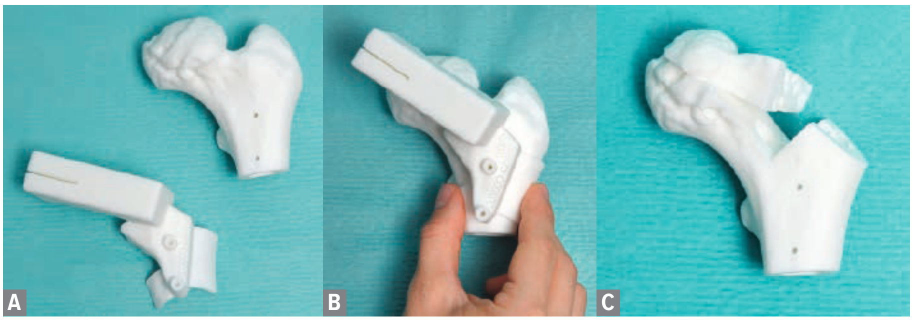

Fig. 4: A) 3-D printed PSI and true-size replica of the pathological femur. B) Verification of the PSI on the replica of the pathological femur. C) Postoperative femur model

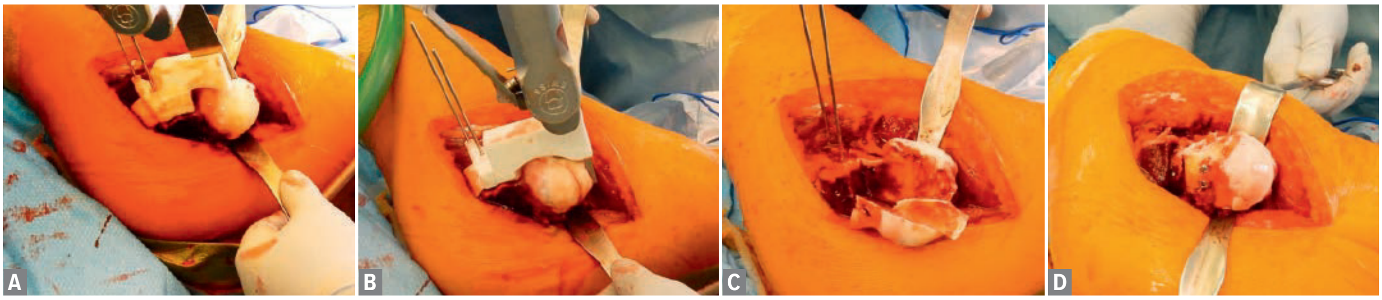

Fig. 5: A) Navigated osteotomy using the first PSI (lateral cut). B) Navigated osteotomy using the second PSI, resulting in a medical cut such that the wedge can be resected. In C) the result after the osteotomies is shown. D) Result after wedge resection and fixation of the fragment in the planned position Fig. 5: A) Navigated osteotomy using the first PSI (lateral cut). B) Navigated osteotomy using the second PSI, resulting in a medical cut such that the wedge can be resected. In C) the result after the osteotomies is shown. D) Result after wedge resection and fixation of the fragment in the planned position

Patient-specific navigation instruments and surgical execution

The CASPA software additionally permits the design of PSI which guarantee a very precise execution of surgical tasks such as drilling, cutting, and reduction (Fig. 4). Each PSI is represented as 3D model and has a dedicated position and function in the preoperative planning. For instance, the PSI for guiding the osteotomies of the FHRO are located anteriorly on the proximal femur shaft. They integrate a cutting slit in which the sawblade can be entered to perform the osteotomy exactly as planned. They key idea of PSI is the undersurface of the instrument base, which guarantees to place the instruments in the surgery on the bone exactly on the same position as preoperatively planned. This can be achieved by computer algorithms which are capable of moulding the undersurface as a negative of the bone surface. Afterwards, a selective laser-sintering device (3D printer) is used to manufacture the PSI as CE-conform medical products (manufacturer: Medacta SA, Castel San Pietro, Switzerland). A biocompatible polyamide PA2200 is used as the raw material for printing.

Before surgery, the PSI are verified on a true-size replica of the pathological femur (see Fig. 4B) and sterilised with conventional steam pressure sterilisation.

The FHRO surgery starts with an exposure of the hip using the surgical dislocation approach,[13] including a trochanteric osteotomy, which enables full access to the joint. The trochanter and hence muscles and ligaments are reattached after the resection. The first PSI is then applied to the femoral shaft and shifted proximally until the optimal position can be found (Fig. 5). The first osteotomy is performed by inserting the saw blade into the slit of the PSI (lateral cut, Fig. 5A). Afterwards, the second PSI is applied to complete the wedge resection (medial cut, Fig. 5B), followed by the reduction of the mobile fragment to its planned position (Fig. 5D). The fragment is secured with three lag screws to the medial part, while two further screws secure the trochanter fragment (Fig. 6).

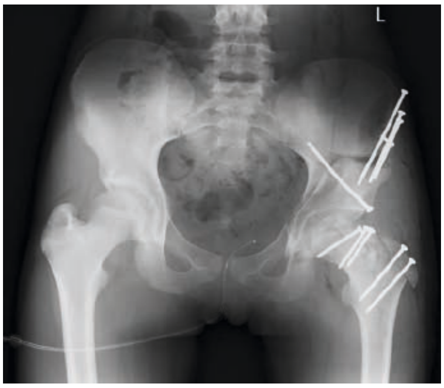

Fig. 6: Post-operative radiographs 7 weeks after the FHRO. A reorientation of the acetabulum was additionally performed in this case to achieve optimal joint congruency

Discussion and outlook

The progress in technology, especially in computer simulation and 3D printing, has enabled the application computer-assisted preoperative planning and surgical navigation in hip surgery. Above all, we see the benefits particularly for FHRO: The precise planning of the osteotomies, which are required to reconstruct the sphericity of the head, is hardly possible on conventional, plain radiographs or single CT scans due to the limitations of 2D based methods. To date, the proposed computer-assisted treatment approach has been successfully applied in five LCP cases. Furthermore, we have initiated a comprehensive clinical trial to investigate the effectiveness of the method more systematically and in a larger setting.

Previous studies have already shown that the application of PSI can result in a significantly improved surgical execution compared to the freehand technique.[10] Therefore, we strongly expect to observe equivalently high precision in PSI-navigated FHRO. Moreover, the more controlled execution of the osteotomies reduces technical failures, which is particularly advantageous in complex interventions. Furthermore, the application of PSI has shown to reduce surgery time,[10] which is beneficial for the patient and reduces costs.

However, there are also limitations to this method. The preoperative time effort to create the 3D simulation and to design the PSI is - with up to 5 hours on average - still very high. Consequently, costs for PSI design amount up to 3000 EUR and manufacturing costs of 600 EUR have to be considered as well. Unfortunately, insurance companies do not reimburse these expenses, because the tariff structure in the Swiss health care system is not yet prepared to consider costs of innovative, new technology within a reasonable time. Another drawback is the long production lead time of 2 weeks, required for 3D printing of the PSI.

Future work will address the development of computer algorithms to automate the planning process such that planning times and costs can be reduced. Furthermore, the consideration of additional image modalities such as MRI will enable the integration of cartilage models into preoperative planning.

The herein presented new computer-based treatment concept for LCP permits sophisticated 3D preoperative planning and a simpler, safer and more precise surgical execution. ■

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NEWS

Neue Ansätze im Kampf gegen infizierte Implantate

Implantatassoziierte Infektionen waren ein Schwerpunktthema auf der Agenda des Deutschen Kongresses für Orthopädie und Unfallchirurgie (DKOU) 2018. Unter anderem wurden neue Ansätze zur Vorbeugung und Behandlung dieser Komplikation diskutiert.

Wundinfektionen nach einer Operation gehören zu den gefürchtetsten Komplikationen in allen chirurgischen Fächern. Auf Implantaten können Bakterien eine dünne Schleimschicht, den sogenannten Biofilm, bilden, der sie vor Angriffen des Immunsystems oder Antibiotika schützt. Ohne Behandlung droht eine Blutvergiftung. «Patienten, die nach einer Operation starke Schmerzen im Wundbereich oder Fieber haben, müssen deshalb so schnell wie möglich untersucht und behandelt werden», betonte Prof. Dr. med. Joachim Windolf, einer der Kongresspräsidenten des DKOU 2018. Meist sind dann mehrere Operationen notwendig, bei denen das Implantat entfernt und die Eingriffsstelle von Keimen befreit werden muss. Bei den besonders schwerwiegenden Formen der bakteriellen Entzündung des Knochens (Osteomyelitis) ist ein interdisziplinärer Therapieansatz erforderlich. «Der Operateur sollte dazu einen Infektiologen, Mikrobiologen und gegebenenfalls einen plastischen Chirurgen mit in die Behandlung einbeziehen», sagt Windolf. Dies empfiehlt auch die aktuelle Leitlinie der Deutschen Gesellschaft für Unfallchirurgie (DGU).[1]

Um das Risiko für Infektionen so gering wie möglich zu halten, empfiehlt Windolf folgende Massnahmen: ein Vorab-Screening auf multiresistente Erreger (z.B. MRSA), strenge Hygiene nicht nur im OP, sondern im gesamten Krankenhaus und möglichst gewebeschonende Operationstechniken. Eine weitere Präventionsmassnahme ist etwa die Verwendung antimikrobiell beschichteten Fadenmaterials oder spezieller antibiotikahaltiger Knochenzemente für die Verankerung der Kunstgelenke. Studien zeigen, dass dieser das Infektionsrisiko deutlich verringert, vor allem bei den besonders risikoreichen Korrektur- oder Wechseloperationen.[2]

Für Platten und Nägel, die bei offenen und somit stark infektionsgefährdeten Knochenbrüchen eingesetzt werden, gibt es Beschichtungen, die die Ansiedlung von Keimen verhindern sollen. In Laborversuchen wird zudem die gezielte Anwendung von Viren, welche sich auf die Zerstörung von Bakterien spezialisiert haben (Bakteriophagen), untersucht. Diese sind in der Lage, in den bakteriellen Biofilm einzudringen und diesen zu zerstören. *(red)* ■

Quelle:

Pressemitteilung zum DKOU 2018, 23.–26. Oktober 2018, Berlin

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